ONSALA RYMDOBSERVATORIUM
CHALMERS TEKNISKA HÖGSKOLA

ONSALA SPACE OBSERVATORY
CHALMERS UNIVERSITY OF TECHNOLOGY

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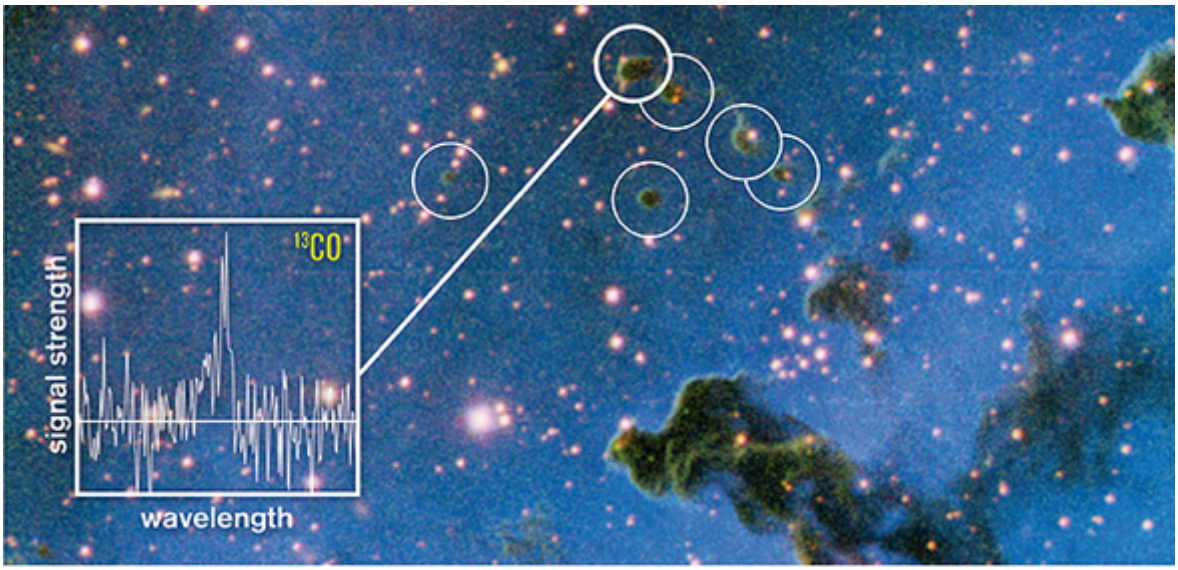
Report on the activities in 2013
Onsala Space Observatory
The Swedish National Facility for Radio Astronomy

This report presents the activities at Onsala Space Observatory (OSO) during 2013; Including the usage of the instruments for scientific purposes, according to the contract for operation of OSO between the Research Council and Chalmers.



Cover Figure – Evidence for interstellar clouds forming free-floating planets (Gahm et al 2013). Molecular line observations of the Rosette Nebula using the 20 m and APEX telescopes have revealed the physical conditions within dense globulettes (circled) suggesting they will form sub-stellar brown dwarfs and planets.

Onsala, February 25th, 2014

John Conway
Director, Onsala Space Observatory

Contents

The report is divided into the following sections:

1) Operations

During 2013 Onsala Space Observatory (OSO) operated the following facilities:

– The Onsala 20 m telescope for astronomical Very Long Baseline Interferometry (VLBI), geodetic VLBI, and single-dish astronomy
– The Onsala 25 m telescope for astronomical VLBI
– The Onsala LOFAR station as part of the International LOFAR Telescope (ILT) and in stand-alone mode
– The Atacama Pathfinder Experiment telescope (APEX) for single-dish astronomy and astronomical VLBI

– The Nordic ARC node (the Atacama Large Millimetre/sub-millimetre Array Regional Centre node for the Nordic, and Baltic, countries)

– The Onsala aeronomy station observing atmospheric H_2O, CO, and O_3,
– Two water vapour radiometers (WVRs) to support space geodesy
– The Onsala gravimeter laboratory for absolute and relative gravimetry
– The tide gauges at Onsala
– The Onsala GNSS stations
– The Onsala seismometer station
– The Onsala time & frequency laboratory

Operations using the above facilities are described in more detail below under Telescopes (Sect 1.1), The Nordic ARC node (Sect 1.2) and the Geophysical instruments (Sect 1.3).

1.1 Telescopes

In general, all telescopes have operated according to the 2013 activity plan without any major problems during the year

-- **APEX --** During the year the instrumentation generally worked with high efficiency. The APEX-3 receiver experienced biasing problems for part of the year (May-Sep), but this problem was resolved in September 2013. The APEX band T2 receiver (1.25 – 1.39 THz) remained non-operational during 2013 due to a faulty mixer, and could not be repaired due to restrictions in the Chalmers Clean Room. Due to the rigorous weather constraints on observing in this band this has had limited impact on the science that can be done with APEX. A new bolometer camera ArTeMiS (ESO PI instrument) was successfully installed and commissioned at APEX in the summer of 2013, partly on Swedish time.

OSO supported observers travelling to the APEX site in Chile for service observing. These observers spent in total 169 man-days on APEX activities (excluding travel and high-altitude medical exam days, but including on-site observing preparations). A postdoc was hired late 2012 to assist with the APEX service observations in 2013. The Swedish APEX data sets now are transferred to the ESO archive; a few days after the observations the PI can directly download them. The data sets become publicly available after one year of proprietary time.

In February 2013 an international review group evaluated the science case for operation of APEX for the period 2015-2017. In their report the review group strongly recommended operation of APEX until at least the end of 2017. An agreement for continuing operations till that date was subsequently signed by all three partners in January 2014.

-- LOFAR -- The Swedish LOFAR station participated seamlessly within the International LOFAR Telescope (ILT) network. The time not dedicated to the ILT (nominally at least 10%) was used in a multitude of ways including (a partially successful) attempt to detect low frequency transatlantic fringes between our LOFAR station and a US antenna. The station was also for the first time employed in an outreach role during the Onsala Stjärnträff (an event within the nation-wide Astronomins Dag och Natt), showing real-time radio images of the entire local sky. A call for proposals was issued in September for PI projects to be carried out during stand-alone time starting in April 2014. Test observations were carried out in 2013 with that goal in mind. Two such 'standalone' proposals for the April deadline were received and accepted.

-- VLBI – Very long baseline Interferometry observations were conducted using the Onsala 25 m and 20 m telescopes as part of international networks of telescopes. The astronomical VLBI observations were scheduled based on recommendations from time allocation committees (the European VLBI Network TAC and Global Millimetre VLBI Array (GMVA) TAC). The International VLBI Service scheduled the geodetic VLBI observations for Astrometry and Geodesy (IVS).

The use of the above telescopes were distributed in the following way (in round terms):

– The Onsala 20 m telescope:	96 days of single-dish astronomy
	14 days of astronomical VLBI
	42 days of geodetic VLBI
– The Onsala 25 m telescope:	58 days of astronomical VLBI
– The LOFAR station has been operational throughout the year	
– APEX telescope	52 days of single-dish astronomy
	(+ 1 day of mm-VLBI)

Time for technical service, pointing, radome maintenance, etc. is not included, and amounts to about 30 and 10 days on the 20 m and 25 m telescopes, respectively.

The time for geodetic VLBI includes 40 regular IVS-sessions in the R1-, RD-, RDV-, T2- and EUR-series plus two dedicated UR-sessions (ultra-rapid) sessions conducted in collaboration with GSI in Tsukuba, Japan.

1.2 Nordic ARC Node

The Nordic ARC provided support to the Nordic and Baltic ALMA communities for both Cycle 0 and Cycle 1 data reduction and analysis and for Cycle 2 proposal preparation. Due to significant technical and weather delays at ALMA during 2013 the Cycle 1 data delivery will mostly occur in 2014. Data reduction for four Cycle 0 and 1 ALMA proposals (with Nordic PIs or co-Is) was supported by Nordic ARC personnel. Additionally, the Nordic ARC performed Quality Assessment on five European (one Nordic) Cycle 1 data sets.

The Nordic ARC also supported the preparation of large number of ALMA proposals for the Dec 6th Cycle 2 deadline. Compared to the previous cycle the number of proposals submitted by Nordic PIs increased by more than 52% (compared to the overall increase from the worldwide community by 22%). Additionally the total number of users from the Nordic/Baltic region (PI or co-I) submitting proposals increased by more than 40% to 110, with 50 unique users from Sweden. To help the community with Cycle 2 proposal preparation, Nordic ARC staff gave a number of tutorials at institutes in the Nordic region (Uppsala/Stockholm, Turku, Copenhagen and Onsala). Over 60 astronomers attended these tutorials.

In May the ARC organized the "Nordic Science with ALMA" workshop at Chalmers University. The meeting was attended by 55 astronomers and featured high-quality presentations related to Nordic ALMA science interests. The ARC staff were also involved in teaching at the "Molecules in Space" summer school held in Onsala (June 24-July 1). This period also saw the launch of a new official Nordic ARC webpage (www.nordic-alma.se) which hosts a variety of data analysis tools developed at the Nordic ARC to support users with their ALMA data.

In support of their duties Nordic ARC node staff travelled to ESO to support the Quality Assessment process of Cycle 0 data products. In March, the ARC node manager attended the ARC face-to-face meeting at ESO. Finally, in November an

ARC member of staff gave a presentation about the ALMA correlator at the Swedish National Committee for Radio science and communication conference in Stockholm.

A fourth computer was installed as part of the National Facility Computer Infrastructure (NAFCI), a computer cluster at Onsala optimized for radio astronomy user data reduction including for ALMA data reduction via the Nordic ARC.

1.3 Geophysical Instruments

In addition to the 20 m telescope, which is used for geodetic VLBI (see Sect 1,1), the following geophysical instruments were operational at OSO during 2013.

- **Aeronomy station:** The aeronomy station performed continuous observations of mesospheric CO and H_2O (except for maintenance periods). The station delivered mesospheric H_2O profiles from 2012 to the Network for the Detection of Atmospheric Composition Change (NDACC).

- **Water Vapour Radiometers:** The two water vapour radiometers Astrid and Konrad measure the amount of water vapour in the atmosphere. Both of them were operating continuously during the year, although Astrid was suffering from a failure of the 31 GHz channel. Until this problem is corrected its data will only be useful during atmospheric conditions with no significant amount of liquid water.

- **Gravimeter laboratory:** The main purpose for the gravimeter laboratory at Onsala is to maintain a gravity reference and calibration facility co-located with space geodetic techniques. The facility is one component of the Onsala Fundamental Geodetic Station. Its primary instrument is a superconducting gravimeter (SCG, model GWR 054). This instrument has been operated with record few breaks (less than 10 days) since its installation in June 2009. The data loss in 2013 was 8 samples in the 1-second record. Since January 2012 the system delivers 1-second data online with two minutes latency at maximum. See http://holt.oso.chalmers.se/hgs/SCG/monitor-plot.html

- **Tide gauges:** A tide gauge based on pressure sensors (the same instrumentation as used by the Swedish Maritime Administration: "Sjöfartsverket") was operated next to the GNSS tide gauge station throughout the year. The data were analysed in various ways and with different methods. Results are included in manuscripts that were submitted in 2013 and are also part of the PhD thesis of Chalmers student Johan Löfgren (which was successfully defended in January 2014).

- **GNSS stations:** OSO's primary Global Navigational Satellite Systems (GNSS) station is also a part of the SWEPOS network operated by Lantmäteriet. Additionally, it is one of the fundamental reference sites used in the global IGS network, as well as in the European EUREF network.

- **Seismometer station:** OSO hosts a seismograph station of the "Svenska nationella seismiska nätverket" (SNSN) at Uppsala University. We have data access to the local seismometer and keep a continuous archive of seismic events.

– **Time & frequency laboratory:** OSO hosts a pair of hydrogen masers which are necessary for VLBI observations. As a by-products these contribute to a network defining the universal atomic time. OSO also collaborates with SP Technical Research Institute of Sweden on a Swedish time-keeping system.

2) Quantitative measures of Reliability

The reliability of the OSO instruments is in general very high. For instance, the downtimes of the telescopes due to technical failures are well below 10 %. The downtimes are instead dominated by weather effects (rain, wind). The efficiency is particularly high for the Onsala 20 m telescope because of the radome enclosure.

In general, the efficiency is difficult to define. In particular, this is the case the astronomical observations were data quality must be taken into account. The quality is for instance sensitively dependent on the (varying) weather conditions, particularly at mm and submm wavelengths. In addition, the efficiency varies strongly with the complexity of the observations. This is particularly noticeable for submm observations at APEX where the overhead for getting data may be a factor of three even in good weather conditions even with no technical issues. In the list below, efficiency is therefore defined as the ratio between the amount of time delivering data (of acceptable quality), including overhead because of telescope movement, pointing, and calibration, and the amount of time allocated to the activity.

– Efficiency of 25 m telescope for astronomical VLBI 90%
(Time lost mainly due to weather)

– Efficiency of 20 m telescope for astronomical VLBI 90%

– Efficiency of 20 m telescope for cm- and mm-wave single-dish 80%
(Time lost mainly due to weather)

– Efficiency of LOFAR station participation in ILT observations 100%

– Efficiency of APEX during Swedish time 62%
(Time lost mainly due to weather: three major snowstorms hit during Swedish time in 2013; excluding weather effects, the efficiency was 95%)

– Efficiency of 20 m telescope for geodetic VLBI 100 %

– Efficiency of superconducting gravimeter 100 %

– Efficiency of aeronomy station, 22 GHz system 90 %
110 – 115 GHz system 25 %
(the new uncooled double-sideband system started taking measurements in October 2013)

-- Efficiency of water vapour radiometers, -Astrid 35 %
(Data taken after the spring is not included
Due to a failing 31 GHz channel)

- Conrad 85 %
(Time lost due to rain)

– Efficiency of GNSS station 100 %

3) User statistics

In this compilation of user statistics 'user' means an author or co-author of a proposal granted observing time during 2013 on an OSO instrument (for the new LOFAR and ALMA instruments 'user' means an author of proposal submitted in 2013);

– Onsala 20 m telescope, single-dish: 35

Of these investigators 16 had Swedish affiliation, 12 had not used the telescope before; the oversubscription rate was about 1.

– APEX (Swedish time), single dish: 233

Of these, 32 had Swedish affiliation, 85 had not used APEX before on Swedish time; the oversubscription rate was 1.8.

– ALMA 110

Number given is number of unique Nordic users on proposals submitted for the Cycle 2 deadline - of these 50 are Swedish.

– Astronomical VLBI: 237

The handling of proposals, scheduling, etc. is done centrally, mainly through the EVN. OSO does not have direct access to all statistics but we have been informed that in 2013, there were 237 individual users of the EVN (including e-VLBI) and GMVA (The Global mm-VLBI Array). Eleven of these had Swedish affiliation. Most VLBI projects included at least one of the Onsala telescopes. The EVN oversubscription rate was 2.6.

- LOFAR: 253 (ILT proposals) / 8 (OSO stand-alone proposals)

The Onsala LOFAR station spends >90% of its time operating as part of European network of antennas and a small amount of time operating as a stand-alone station. For the former proposals are submitted centrally to the ILT (International LOFAR Telescope) with headquarters at ASTRON in the Netherlands. Within this time the Executive committee of the LOFAR-Sweden consortium (freely open to membership to all Swedish scientists, see http//lofar-se.org) allocates the Swedish guaranteed time (4.5% o the total). The Cycle 1 deadline (September 6 2013) had 4 unique Swedish applicants but these were in involved in a large fraction (14/55) of the projects submitted. Basic functionality for Onsala LOFAR station standalone observations was offered for the Oct 15th OSO deadline. Submitted proposals for this deadline involved 8 users of which 3 had a Swedish affiliation.

The following instruments deliver data through various archives:

- Geodetic VLBI: Observations are performed as a service to the global geodesy community, i.e., the observations are not performed for particular scientific projects; given this it is not possible to give the number of users. Geodetic VLBI defines the global geodetic reference system, which is used by a very large number of research projects (e.g., in remote sensing). It can be noted though, that 7 refereed publications were based on geodetic VLBI data including the Onsala 20 m telescope in 2013.

- The Onsala Aeronomy Station: Data from 2013 onward is now processed to be delivered through the Network for the Detection of Atmospheric Composition Change (NDACC).

- Gravimeter Laboratory: Through an http address, gravimeter data with 1-second samples and maximum two minutes latency is available to practically everyone. This has been an effort to serve EPOS, the European Plate Observing System. The data can be UDP-multicasted as soon as a dedicated IP-address is assigned. On a monthly basis, 1-minute data is transferred to the Global Geodynamic Project's archive at Geoforschungszentrum Potsdam, Germany. GGP is a collaborative effort, an Inter-commission Project of the International Association of Geodesy (IAG).

- The GNSS data are available through the SWEPOS (http://swepos.lmv.lm.se/), and International GNSS Service (IGS) (http://igscb.jpl.nasa.gov/) archives.

4) Peer-reviewed papers

The list below give the number of papers in refereed journals based on the OSO instruments appearing in 2013 (the numbers are minimum, publications may have been missed):

- Onsala 20 m telescope, single-dish: 5
- APEX, single dish[1]: 74
- SEST, single-dish[2]: 12
- ALMA[3] 6
- Astronomical VLBI: 25
- LOFAR[4]: 8
- Odin astronomy[5]: 1
- Odin aeronomy[5]: 8
- Geodetic VLBI[6]: 7
- GNSS, tide gauge, gravimeter, radiometers[5]: 3

1) Includes Swedish, ESO and MPI time
2) The Swedish-ESO Submillimetre Telescope (SEST), an equal collaboration between ESO and OSO was taken out of operation in 2003.
3) These are ALMA papers in which the Nordic ARC node helped the authors with observation preparation or with data reduction.
4) In addition, there are a large number of publications discussing future observations with LOFAR.
5) Odin astronomy and aeronomy is mentioned here since OSO played a technically important role in this satellite project.
6) These data are also used in other ways than scientific publications. It is one of the main goals for geodetic VLBI to define the global geodetic reference system, which is used by a very large number of research projects (e.g., in remote sensing from ground and space accurate positioning is often a necessity). In a similar way GNSS data define geodetic reference frames for regional scales (land surveying).

There are additional to the above papers a further five refereed publications by OSO staff on R&D for mm/submm instrumentation, LOFAR, SKA, antenna systems, etc.

5) Selected scientific highlights

Below follows a list of scientific highlights selected to illustrate the different instruments and science areas covered by OSO.

Astronomy

5.1 Onsala 20 m single dish

Gahm et al. (A&A, 555, A57, 2013) used both the OSO 20 m telescope and the APEX telescope (see cover figure and Fig 1) to survey a large number of small clumps ("globulettes") surrounding the Rosette Nebula for their molecular gas content and dynamics. The main conclusion is that many of the globulettes will escape the parent nebula and form dense cores thus having the potential to form free-roaming brown dwarfs or planets.

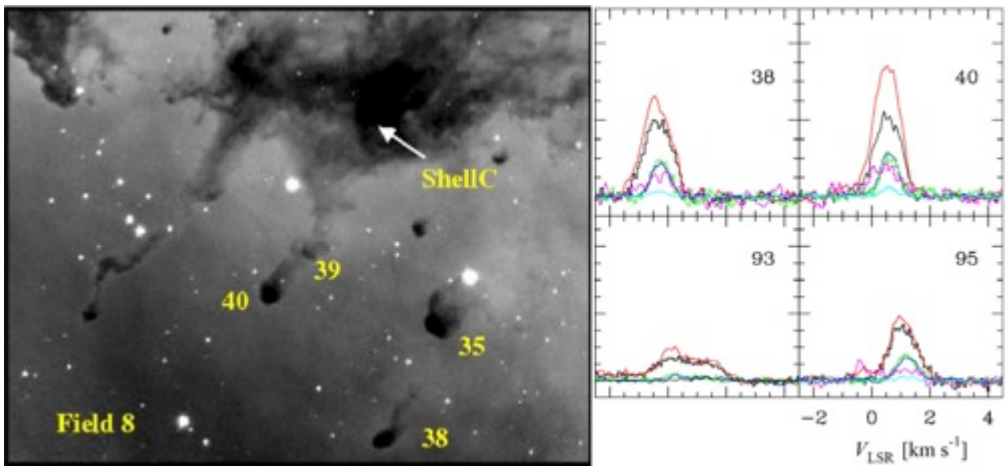


Fig 1. Observations of globulettes in the Rosette Nebula (Gahm etc al 2013). Left: Halpha image of a sample region within the Rosette Nebula. Right: CO & 13CO example spectra from the OSO 20 m and APEX telescopes. Two of the Globulettes are visible in the Halpha image (labelled 38 and 40).

Cordiner et al. (ApJ, 770, 48, 2013) observed the HC_3N (J=10-9) lines at 91.0 GHz with the OSO 20 m telescope aiding the interpretation of observations of large carbon chain anions (discovered relatively recently in the ISM). These observations showed that the ionization fraction of these species varies with molecular hydrogen density for different types of objects suggesting that formation process for some of the anions needs to be revised.

During 2013 a record four comets were observed using the OSO 20 m telescope by a local team supported by informal contacts with leading scientists in cometary science. These observations yielded detections of the HCN (J=1-0) molecular line, indirectly tracing the gas production rate in three of the comets namely Panstarrs, ISON, and Lovejoy. The latter comet also yielded a probable detection of CS and a time curve for the HCN line intensity and hence gas production rate (see Fig 2).

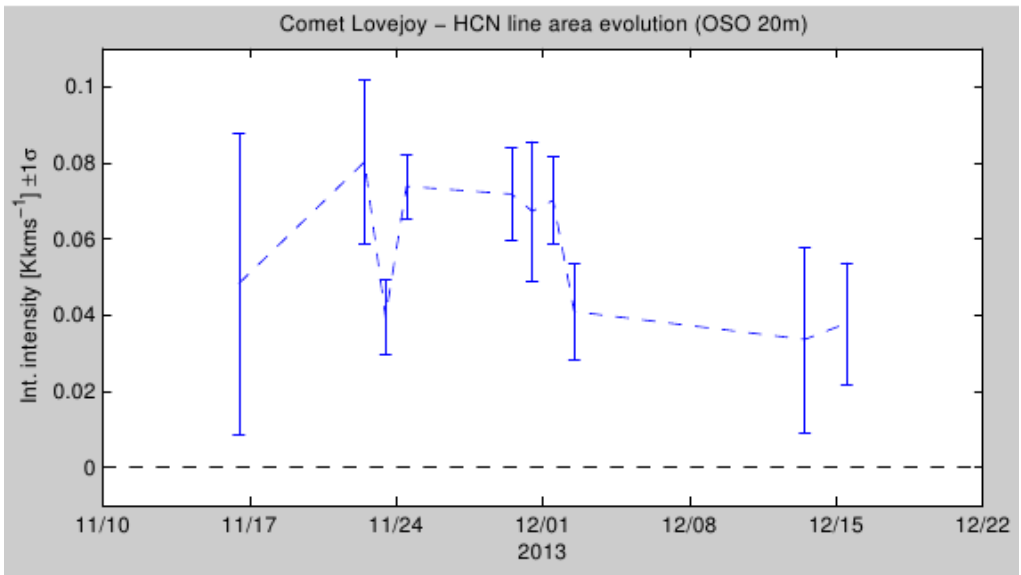


Fig 2. Preliminary HCN(J=1-0) line intensity versus time data for Comet LoveJoy as observed using the 20 m telescope during 2013.

5.2 VLBI Studies

Despite the recognized importance of magnetic fields in the formation of low-mass stars their role in the formation of high-mass stars is still under debate. Surcis et al. (A&A, 556, 73, 2013) reported results from a long-term EVN program of polarization observations of the 6.7 GHz methanol maser emission in young stellar objects (YSOs). This program has brought the first opportunity to analyze statistical properties of a representative YSO sample. Analysis has revealed the first statistical evidence that the magnetic field on scales 10-100 AU is primarily oriented along the large-scale outflow direction

Miller-Jones et al. (Science, 340, 950, 2013) used the triggered e-VLBI capability of the EVN to study of the prototypical dwarf nebula, SS Cygni. The main aim of the project was to measure its distance via parallax since the value obtained with the Hubble Space Telescope makes the source much too luminous according to models. The authors report an accurate model-independent distance to SS Cygni, based on EVN and VLBA data of 114 +/- 2 parsecs (Fig. 3) compared to the Hubble Space Telescope distance of 159+/-12 parsecs. This closer distance reconciles the source behavior with the understanding of accretion disc theory in accreting compact objects.

Morganti et al. (Science, 341, 1082, 2013) used global VLBI spectral line observations to study the nucleus in the galaxy 4C12.50. The high-resolution images (Fig. 4) resulting from theses observations allowed a determination of the location of the gas outflow and a determination of the speed at which the gas leaves the galaxy. This is the first clear evidence showing that jets powered by a supermassive black hole in the centre of a galaxy can clear gas away from that galaxy. This may be the mechanism that converts a gas rich star-forming galaxy into a 'red and dead' elliptical galaxy.

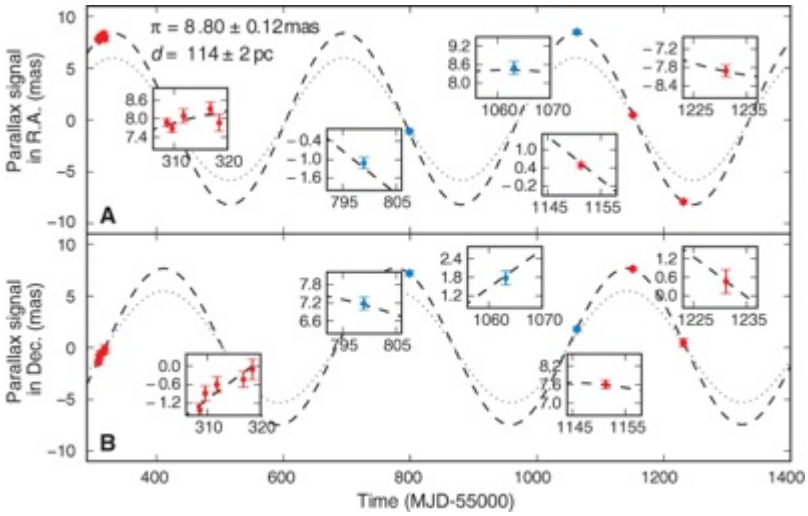


Fig 3. VLBI Parallax observations of the dwarf nebula source SS Cygni (Miller-Jones et al 2013). (A) Right ascension; (B) declination. Red points show VLBA measurements; blue points show EVN measurements.

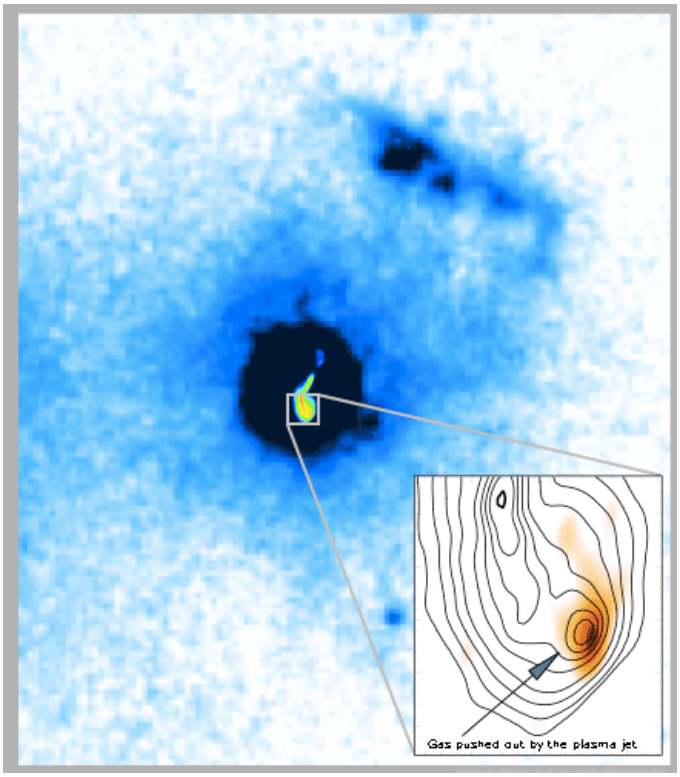


Fig. 4. A jet driving gas outflow in the galaxy 4C12.50 (Morganti et al 2013). An optical image of the galaxy is shown in blue. The inset shows a zoom in of the plasma jet and the cold atomic hydrogen gas (orange). The gas is distributed in a compact cloud (dark orange) and filaments (light orange) as result of the strong impact with the plasma jet.

Very sensitive, wide-field observations (Chi et al. 550, A68, 2013) of the *Hubble* deep field North (HDF-N) and surrounding Hubble flanking fields (HFFs) with a global VLBI network including the Onsala 25 m telescope have uncovered a large population of black holes residing in the centres of dust obscured galaxies (see Fig 5). Compact AGN powered radio sources are found in 12 galaxies. These cores are detected in one quarter of the parent radio source sample. Most, but not all of these low power AGN have X-ray detections; however in some cases the amount of foreground gas absorption is so large that even X-rays from the accreting black holes are absorbed in these systems. The main conclusion is that the majority of the faint radio source population must be star-forming galaxies, although a minority are AGN powered and some of these have such high obscuration that they are X-ray absorbed.

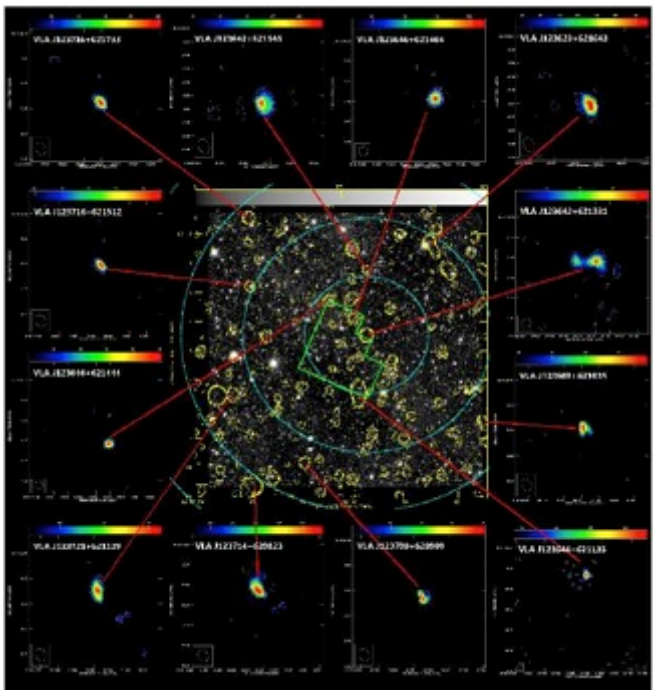


Fig 5. From Chi et al (2013) Composite image of the radio (WSRT 1.4 GHz) – optical overlay image of the HDF-N and HFF, surrounded by postage stamp images of the twelve compact VLBI-detected radio sources.

5.3 International LOFAR Observations of Starburst Galaxy M82

Chalmers PhD student Eskil Varenius. produced one of the first images (see Fig 6) made with the international baselines of LOFAR (including the station at Onsala), of the nucleus of the starburst galaxy M82. The resulting image at 150MHz (or 2m wavelength) is the most sensitive high-resolution (0.5'' FWHM) image ever produced at this frequency. The image shows diffuse emission arising from outflows from an edge-on star-forming disk of 100pc diameter plus numerous compact sources arising in Supernova Remnants (SNRs). The continuum spectral shapes of these SNRs are being studied to distinguish between models having respectively internal or foreground free-free absorption.

5.4 APEX Observations

The LABOCA and SABOCA cameras operating respectively at 870 um and 350 um wavelengths produced a spectacular image (see Fig 7) of the Orion nebula showing that the dust clouds form complex sheets, filaments and bubbles (Stutz et al ApJ 767 36S). These structures are likely caused from the combined processes of gravitational collapse and stellar winds. Some 15 compact sources within the image were found to be much brighter at longer wavelengths than at shorter wavelengths indicating that they are very young proto-stars.

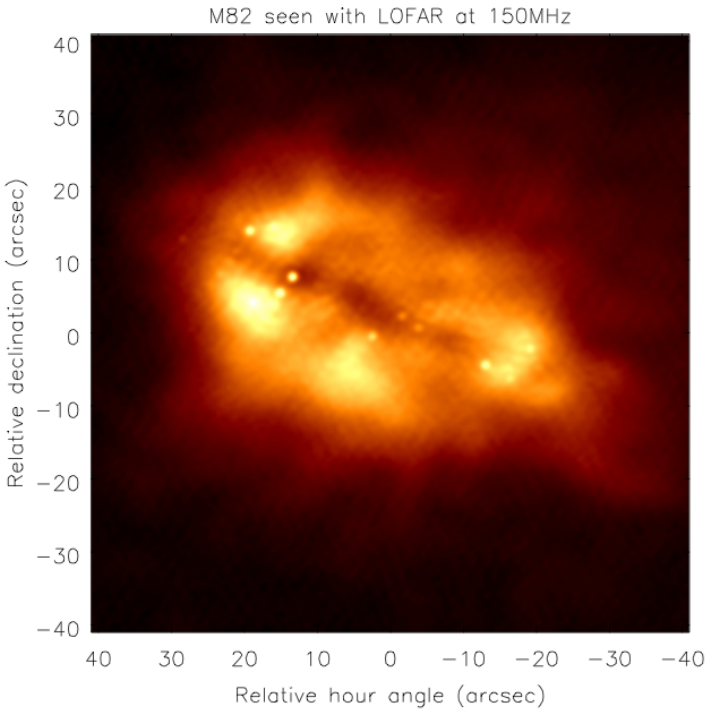


Fig 6. High spatial resolution (FWHM 0.5'') image of the starburst galaxy M82 at 150MHz (2m wavelength) produced during 2013 by the international LOFAR telescope including data from the Onsala LOFAR station (PI Eskil Varenius). The diffuse emission represents outflows from an edge-on star-forming disk and the compact sources the remnants of the supernova explosions that power this outflow.

Fig 7 Dramatic image of dust clouds in the constellation of Orion created from observations using the LABOCA and SABOCA instruments at APEX (Stutz et al 2013)

The APEX SHeFI receiver was used to establish the presence of carbon monoxide (CO) in galaxies with very little oxygen content (Elmegreen et al. Nature 495, 487). These observations indicate a CO fraction of molecular gas which is only 3% of that of the Milky Way. This result poses interesting questions on how stars can form in low-metallicity galaxies and in the early Universe when the metallicity was low.

Liseau et al (AA 549, 7) made the first detection of a temperature minimum in the corona of a solar type star (α Centauri A) other than the Sun, providing important information for modeling extended stellar atmospheres. This result was found by combining Herschel satellite data with APEX LABOCA data. These data also provide a detailed mapping of the IR- submm stellar spectral energy distribution of solar type stars, crucial information when searching for Kuiper belt-like dust emission around other stars from the spectral excess they contribute.

Justtanont et al (AA 556, 101) estimated mass loss rates as a function of radius for five extreme evolved OH/IR stars. These mass loss rates were made combining CO observations from the Herschel Space Observatory with those from the ground-based telescopes including archival APEX data.

Moullet et al (2013, ApJ 776, 32) made the first detection of the molecule $^{34}SO_2$ and a tentative detection of KCl in the atmosphere of Jupiter's moon Io using the APEX SheFI receiver.

5.5 ALMA Observations

ALMA observations of molecular emission from the supernova remnant SN1987A (see Fig 8) resulted in the first ever detection of a very large mass of cold molecular CO in the ejecta of a supernova (Kamenetzky et al 2013, ApJ, 773 L34). This is the first detection of pure rotational CO , which probes gas of less than 100K, in SN1987A making this by far the coldest gas ever detected in a young supernova remnant. Additionally, the imaging capabilities of ALMA show that the cold CO molecules are located in the expanding ejecta and not in the surrounding circumstellar ring (other facilities cannot distinguish the spatial locations of cool dust). Current formation models for CO in the ejecta of SN1987A fall short by an order of magnitude in their predicted CO masses compared to the observationally derived mass of CO. This discrepancy indicates the need for a re-examination of the theoretical framework of molecule formation in supernovae.

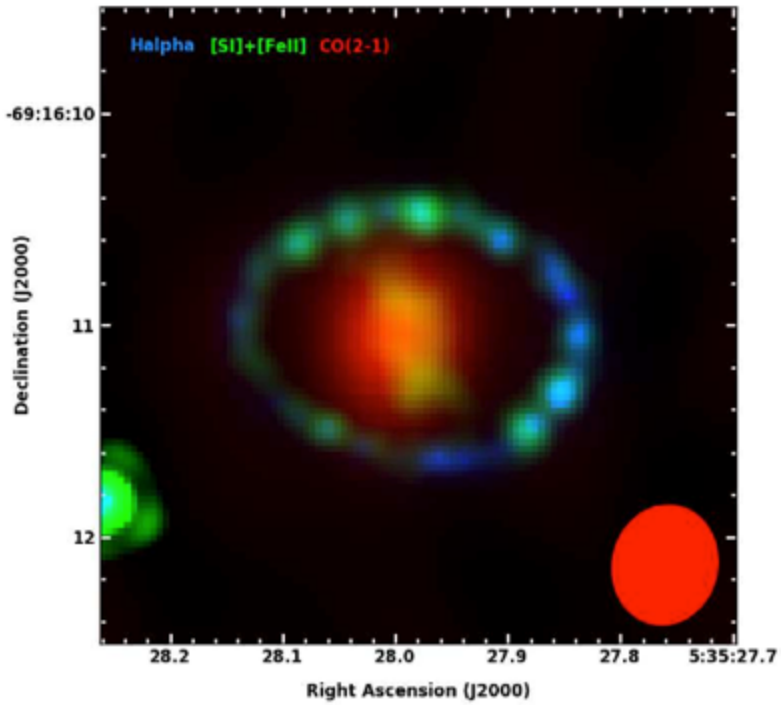


Fig 8. ALMA detection (Kamenetzky et al 2013) of cold CO gas in the ejecta of supernova remnant 1987A. Red shows the CO(2-1) emission from ALMA, blue for H-alpha and green from [Si I]+ [Fe II] lines.

ALMA observations of the lensed blazar PKS1830-211 (originally aimed at the study of molecular absorption from the lensing galaxy) resulted in the serendipitous discovery (Marti'-Vidal et al 2013, A&A, 558, 123) of a sudden flare in the submm wavelength regime, correlated with an increase by a factor ~7 in the gamma-ray emission from the blazar. The chromatic (i.e., frequency-dependent) evolution of the flare was modeled as an event of injection of plasma from the black hole into the base of the jet. This is the first time that such an event (the submm counterpart of a gamma-ray flare coming from the base of a blazar jet) has been observed with such a high sensitivity and wide frequency coverage.

Geosciences

5.6 Coastal sea level observed with a single geodetic GPS receiver

Data recorded with the GNSS tide gauge at the Onsala Space Observatory were analysed and used to investigate whether a single geodetic GPS receiver can be used to observe coastal sea level and its variations (see Fig 9). The comparison of sea level derived with the two-antenna installation at Onsala and sea level derived with just the upward looking antenna showed that the results of the two approaches agreed well. The two-antenna analysis method provides however a slightly better RMS agreement but is more sensitive to the sea roughness (and hence wind speed) when comparing the results to independent tide-gauge records. (Adv. Space Res., 51 (8) 1301-1310).

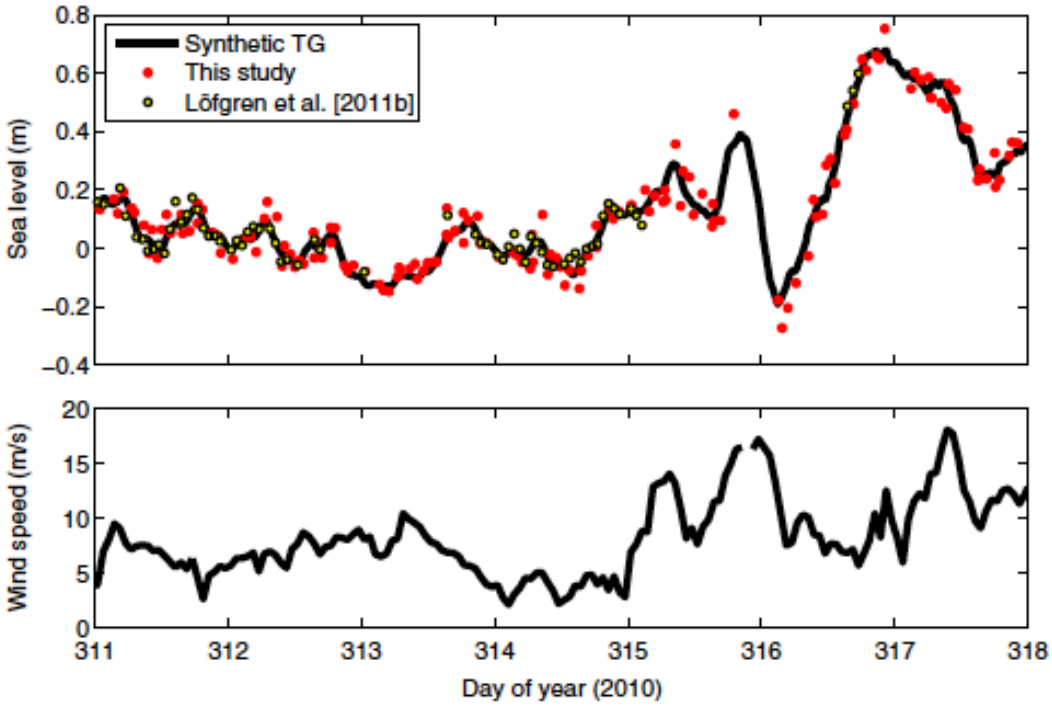


Figure 9. Top: Synthetic tide gauge record (black line), the GPS tide gauge results from a single geodetic receiver (red dots), and the GPS tide gauge results from a two antenna installation (yellow dots). Bottom: recorded wind speeds at Onsala Space Observatory.

5.7 Geophysical parameters of solid earth tide models determined from geodetic VLBI

The 27 year long global geodetic VLBI data set observed between 1984 and 2011 was analysed to determine complex frequency-dependent geophysical parameters that describe solid earth tide effects. The results deviate slightly from conventional values using theoretical Earth models. The maximum deviations for 12 diurnal tides are on the order of 1 to 2 mm for the horizontal and radial displacements. (J. Geodyn. 70, 21– 27).

5.8 Free Core Nutation studies with geodetic VLBI

Several research groups studied the effect of Free Core Nutation (FCN) using the global geodetic VLBI data set. Krasna et al. used the global geodetic VLBI data set to determine the period of the FCN from a joined analysis approach using the effects on solid earth tide deformation and nutation. The derived result deviates slightly from a conventional model. The relation between the geomagnetic field and free core nutation was also studied. Malkin (2013) who determined FCN models based on VLBI results for the Celestial Pole Offset (CPO) and related the models to rapid changes in the geomagnetic field secular variations, so-called geomagnetic jerks (GMJs). A high degree of correlation between GMJs and changes of amplitude and phase of the FCN were detected and time lags of 1 to 2 years observed. (A&A 555, A29).

5.9 Crustal motion in Europe from geodetic VLBI

A >20 year data set of purely European geodetic VLBI sessions was analysed to estimate the crustal motion in Europe (Krasna et al., 2013 Acta Geodaetica et Geophysica, 48 (4), 389-404). The results reveal a high degree of agreement with corresponding results derived from a much denser GNSS network. Signatures of global glacial adjustment in the Northern part of the European geodetic VLBI network and the collision of the African plate with the Eurasian plate in the southern part of the European geodetic VLBI network are clearly detected.

5.10 Tropospheric delay modelling for space geodesy

A new empirical seasonal model for tropospheric atmospheric delays was tested using the global geodetic VLBI data set. The results show that this new model is significantly better than previous empirical models and reduces in particular the annual and semi-annual station displacements. However, the new model does perform worse than a tropospheric delay model based on a global numerical weather model. (Geophys. Res. Lett., Vol. 40 (6), 1069-1073)

5.11 Superconducting gravimeter

Periodograms of five day long records from the OSO superconducting gravimeter are shown in Figure 10. Such periodograms are sensitive to variations in local gravity strength on timescales of minutes to days. Results are shown (grey and black curves respectively) for the period of 5 days before and after a major earthquake in Russia. The detected signals in the post earthquake data with periods below 54 minutes arise from spheroidal eigenresonances of the Earth's mantle. The nonlinear ocean tide response in the Kattegat sea is responsible for the occurrence of a strong tide M_6. These data were searched without success for the elusive Slichter mode triplet (Coriolis splitting of translational oscillations of the inner core of the earth, with retrograde, axial and prograde). We show in Fig 10 two sets of solutions for Slichter mode frequencies (Rieutord, 2002 Phys. Earth Planet Int., 11, 269-278; Crossley et al., 1992, Geophys. Res.Letters, 19, 1679-1682). Unfortunately theses modes are not detectable in our data due to the measurement noise and being masked by the M_6 tidal signal. The tide research community has been searching for these modes after large seismic shocks for many decades, and their elusiveness notwithstanding the phenomenon continues to motivate members of the Global Geodynamics Project. Unfortunately, the appearance of nonlinear harmonic products of lunar tides in the Kattegat, especially the relatively strong M_6 tide (third upper harmonic of the principal, semi-diurnal lunar tide) presents a limitation to finding Slichter modes at Onsala.

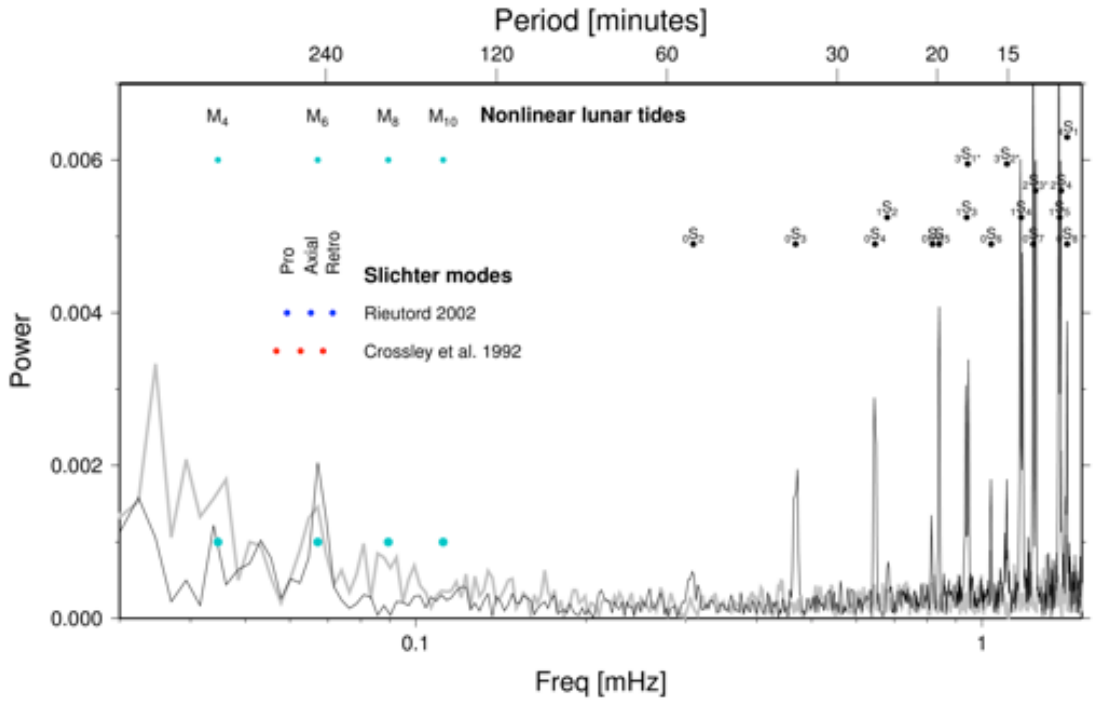


Figure 10. Gravimeter data (black curve) showing Earth free oscillations observed for five days after the M8.2 earthquake on May 24, 2013, 05:44:49 UT deep below the Sea of Okhotsk (N 54.9°, E 153.3°, D 608.9 km), shown as a black curve. The grey curve shows as a baseline the spectrum from six to one days before the earthquake. One power unit is 60 nm/s² per Hz. The symbols pertaining to periods below 54 minutes signify spheroidal eigenresonances of the Earth's mantle. The nonlinear ocean tide response in the Kattegat Sea is responsible for the occurrence of a strong tide M_6, the third upper-harmonic of the principal lunar tide. Free oscillations of the solid inner core, the so-called Slichter modes, have been searched for in the tide research community since many decades, this is another null result.

6) Technical R&D

6.1 Millimetre/sub-millimetre devices.

The OSO Group for Advanced Receiver Development (GARD) carries out research and development work on mm and submm receivers and their components in order to maintain the observatory at the forefront of technology. These technological developments are directly incorporated into the receivers that GARD builds for the Onsala 20 m telescope, APEX and ALMA.

GARD has from June 2012 been involved in a three year EU funded RadioNet3 Joint Research Activity (JRA) AETHER to work on advanced IF components for sideband-separating (2SB) SIS mixers for array receivers. This work is done as a part of collaborative effort with IRAM, which is responsible for the mixer development, while GARD provides the IF hybrid development, design and fabrication. In particular, GARD is working on 4 – 12 GHz solid-state superconducting IF hybrids for such receivers. A new generation of superconducting IF hybrids covering 4 - 8 GHz with improved amplitude and phase imbalance, below 0.6 dB and 2 degrees, respectively has also been developed, fabricated, and tested by GARD. This 4 - 8 GHz hybrid uses superconducting transmission lines, and a built-in bias-T, and it is fully compatible with the ALMA Band 5 and Onsala 3 mm receiver designs. Using a

similar approach, GARD has also designed a 4 – 12 GHz hybrid. A chip implementing this design has been fabricated and tested during 2013 and a paper submitted to an IEEE journal and accepted.

Another important component of mm receiver systems is the RF-waveguide hybrid; this component can have a high impact on receiver sideband rejection and hence final receiver sensitivity. GARD has developed an innovative RF hybrid design; 3D electromagnetic simulations show this has very good performance with an amplitude imbalance <0.4 dB and a phase imbalance <4 degrees A hybrid of this type for the 163 – 211 GHz band was experimentally verified during 2013 and a paper submitted to an IEEE journal. GARD is also working on a new generation of low-noise HEMT amplifiers for 4 – 8 and 4 – 12 GHz. During 2013 this work was complicated by the non-availability of Indium Phosphate transistors (to be supplied by the Department of micro-technology and nanoscience at Chalmers). In order to make progress GARD has developed a prototype employing commercially available GaAs HEMT.

GARD has developed and demonstrated a new approach to construct THz Hot Electron Bolometer (HEB) mixers, where the active element is micro-machined using a so-called π-frame, and the waveguide is micro-machined using a moulding technique with thick photoresist. These technologies are now being implemented in the second generation of the APEX T2 receiver, 1.25 – 1.39 THz. Research was also done on the deposition of ultra-thin NbN films, which are used to make HEB mixers. GARD produced NbN films having critical temperatures between 9 and 13.5 K with a sharp transition from normal to superconducting state within 0.2 K. The paper describing the film deposition technique and the film properties has been submitted and accepted for publication in the Journal of Applied Superconductivity.

GARD has also performed measurements on the first chip using an SIS multiplier (see Fig 11). The proof-of-concept experimental chip has demonstrated a multiplication of a factor of two for frequencies around 200 GHz. A paper has been submitted and accepted to a IEEE journal.

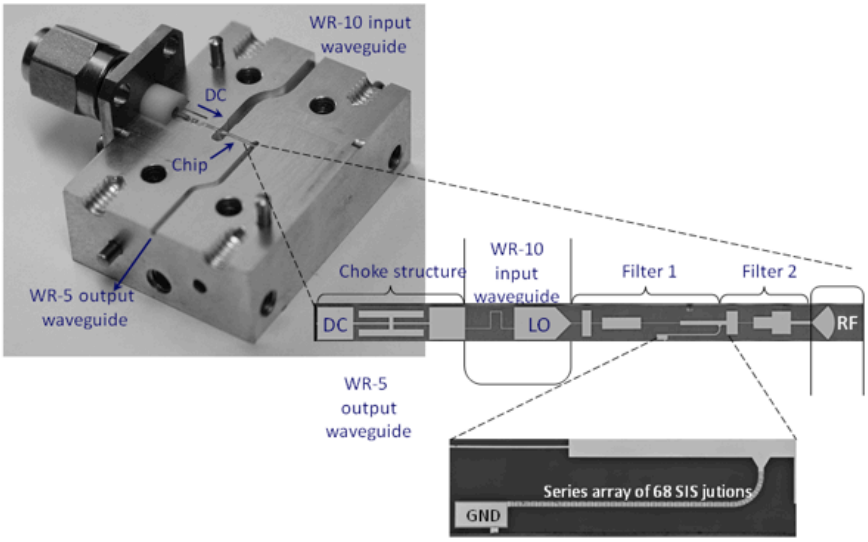


Figure 11. Photograph of the first ever SIS mixer multiplier (see Sect 6.1) with the details of the multiplier mount, the chip and the measured spectra.

6.2 LOFAR

An upgrade was made in the capabilities of the Onsala LOFAR station to record raw antenna signals. This change allows so-called 'LOFAR VLBI ' in which the station can be correlated against other stations not connected in real time to the central correlator. The Onsala LOFAR station participated in test observations to test this technique involving the LOFAR ionospheric station KAIRA in Finland and the Long Wavelength Array (LWA) station in New Mexico, USA. The resulting recorded data was shipped from Onsala electronically and correlated in a software correlator. These experiments were partially successful.

6.3 VLBI

The EU funded NEXPReS project on VLBI over networks concluded successfully at the end of June 2013. NEXPReS made significant improvements to the EVN services and pioneered high-bandwidth, high-capacity networked storage on demand. A successful demonstration of 4 Gbps e-VLBI capability was made on September 18 as part of the final review of the project, using five telescopes of the EVN (including the Onsala 20 m telescope). The international review panel, nominated by the EC, rated the third and final year of NEXPReS with the highest grade of 'excellent'. The next step is to fully implement components from NEXPReS into normal EVN operations.

During the year work continued at Onsala within the EU Radionet3 Joint Research Activity DIVA (developments for VLBI in Astronomy). This project has two parts, both of which OSO is involved in. The first part concerns developing wideband feeds for VLBI. The second part involves the design and testing of the third generation of a digital backend system (DBBC3). The aim is to fully implement digitally all the functionality required of a complete 32 Gb/s VLBI backend for the EVN and for the future geodetic VLBI system VGOS (VLBI2010 Global Observing System).

RadioAstron, the Russian VLBI antenna in orbit, was launched in 2011 and now regularly observes with ground antennas including the Onsala 25m telescope. By providing longer baselines than are possible on the Earth Radioastron increases the angular resolution of the VLBI technique. During 2013 OSO participated in EVN plus RadioAstron astronomical observations with the 25 m telescope and at the same time observed the RadioAstron satellite itself with the 20 m telescope (at X-band) in order to provide crucial orbit determination data.

OSO staff have also worked on the development of a phased array mode for the JIVE software correlator. In this mode the signals from all stations in an experiment are summed coherently rather than being correlated. The main applications of the phased array mode are time domain pulsar studies such as pulsar timing and pulsar searching experiments. Compared to single dish observations the increased signal to noise obtained from the phased array mode yields higher precision timing information and allows for the detection of weaker pulsations. A disadvantage is that the synthesized beam of the phased array is very small and so the field of view of the resulting dataset will be limited. To overcome this limitation a multiple phase centre capability for the phased array correlator mode is under development.

6.4 ALMA Phasing Project

The ALMA Phasing Project (APP) will enable the combination of all the signals from all dishes to one signal so that ALMA operates like a single dish with very large collecting area. Such an ALMA phased array will be used as part of VLBI or for pulsar observations. One important issue in the APP concerns the calibration and conversion of the polarization signal. Most VLBI stations record the signals in a circular basis, but the ALMA antennas observe in a linear basis. The strategy that will be followed in the APP observations will be to correlate the data between ALMA and other telescopes in a "mixed" basis (i.e., correlate linear versus circular) and then convert the results into a pure circular basis after correlation. In this approach, the effect of the different polarization-dependent gains of each ALMA antenna on the phased signal may limit the dynamic range and polarization purity of the final VLBI data. As part of the OSO participation in the APP we have at OSO developed a novel software package, PolConvert, based on the Measurement Equation, to perform the full polarization conversion of the APP data. We have successfully applied our algorithm to realistic simulations of ALMA VLBI observations using the available computing resources at OSO with good results (see Fig 12).

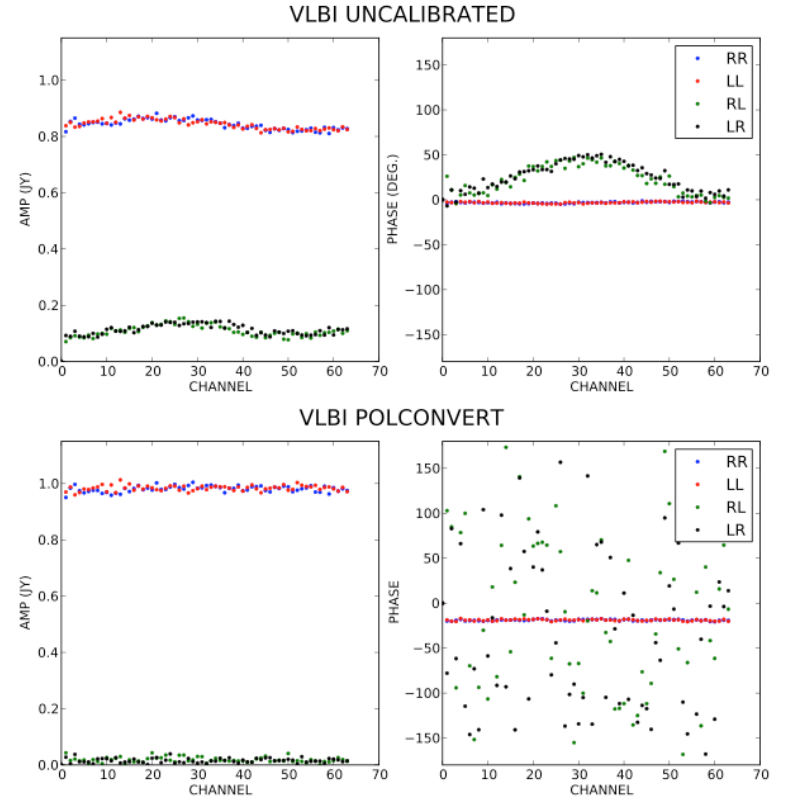


Fig 12. Simulated Phased ALMA to VLBI station visibility of a strong un-polarized source at 100GHz, using realistic gains, bandpasses, and leakage terms for the ALMA antennas. Top: after conversion using a standard polarization matrix. Bottom; after using the OSO developed calibration algorithm "PolConvert".

7) Instrument development and upgrades

7.1 New L/C band receiver for the 25 m telescope

During 2013 a new L/C (6cm/18cm wavelength) band front-end receiver was built and installed on the 25 m telescope (to be used primarily for VLBI). The L-band channel uses the same components as the previous decommissioned receiver, while for the C-band channel the room temperature polarizer was replaced with a cryogenic Ortho-Mode Transition (OMT) purchased from NRAO combined with a commercial 90-degree hybrid to achieve circular polarization. The new receiver reduced the noise figure at 5GHz for the 25 m telescopes from 1300 Jansky for the old receiver to 700 Jansky and also gave improved polarization performance.

Fig 13 Left: Image of new C/L Band receiver assembly for the 25 m telescope. Right-condcting hot load/cold sky tests of sensitivity.

7.2 3mm and 4mm Receiver for 20 m telescope

During 2013 GARD completed the design of a new dual band 3mm/4mm receiver for the 20 m telescope. The 3mm channel of this receiver users a sideband separating mixer (purchased from IRAM) while the 4mm channel uses a low noise amplifier (bought from NRAO). At the first stage in construction only the 3mm channel has been installed. This receiver uses a new design of on/off switch and has built-in cold calibration loads. The receiver, including the cryostat, optics, IF amplifiers (built by GARD) was integrated and initially tested at GARD at the end of 2013. The OSO Electronic Lab (EL) has for this receiver developed a control system and has designed and fabricated a new Phase Lock Loop (PLL) for the Local Oscillator (LO). This new design provides better phase stability for the LO which should result in improved stability of the spectral baselines. GARD together with the EL has fabricated, assembled and tested a new amplifier and mixer bias board that is more compact than the previously used control system and will allow more space in the telescope cabin. The 3mm receiver will be commissioned on the Onsala 20 m antenna during 2014. In

preparation for the planned installation of the 4mm channel later in 2014 the EL has designed and started testing frequency down convertor solutions.

Fig 14. Photograph of the new 3mm/4mm receiver under test at the Onsala Electronics Laboratory.

7.3 LOFAR

An Onsala designed and built test transmitter system was installed at the Onsala LOFAR station to more easily allow calibration of the station. This system has subsequently been copied at other international LOFAR stations. A 10 Gbit/s link was added between the station and the Onsala main building and as part of a Masters thesis tests done on temporary recording and offline reduction of 'standalone' station data. This option was offered as part of the Onsala call for proposals in October and was handled by a modified version of the Northstar proposal handling system. Haarlem et al. (A&A,556, A2, 2013) presented a technical overview of LOFAR to which Onsala contributed.

7.3 VLBI Equipment

During the year several Geodetic VLBI sessions were recorded in parallel with the old Mark4/Mark5A and the new DBBC/Mark5B+ systems and the results successfully cross-validated. Given these successful tests the DBBC/Mark5B+ system is now used for production VLBI observations since December 2013 and the Mark4 has been retired. In September 2013 a second DBBC unit was ordered, with provisional delivery in April 2014, which we hope to put in into operation for the long geodetic CONT14 session. Additionally in preparation for this session we have prepared a new flexible computer controlled IF distribution unit This unit allows us to connect the VLBI recording rack either of the Geo-VLBI

receivers on the 20 m and either of the ASTRO-VLBI receivers on the 20 m and 25 m antennas using the two DBBC units in various configurations.

7.4 Upgrade of the 20 m S-band receiver to second polarization

The current S-band (2.3GHz Band) receiver (mostly used for geodetic VLBI) has only a single circular polarization channel. It was decided to upgrade the receiver to dual circular polarization. A Low Noise Amplifier was purchased from the Spanish company TTI. The Cryogenic box accommodating the LNAs for X- and S- was modified for integration of new polarization channel and the new S-band LNA (see Fig 15). The performance of the receiver (excluding warm part) was verified in the lab and the receiver was installed back on the telescope in November 2013.

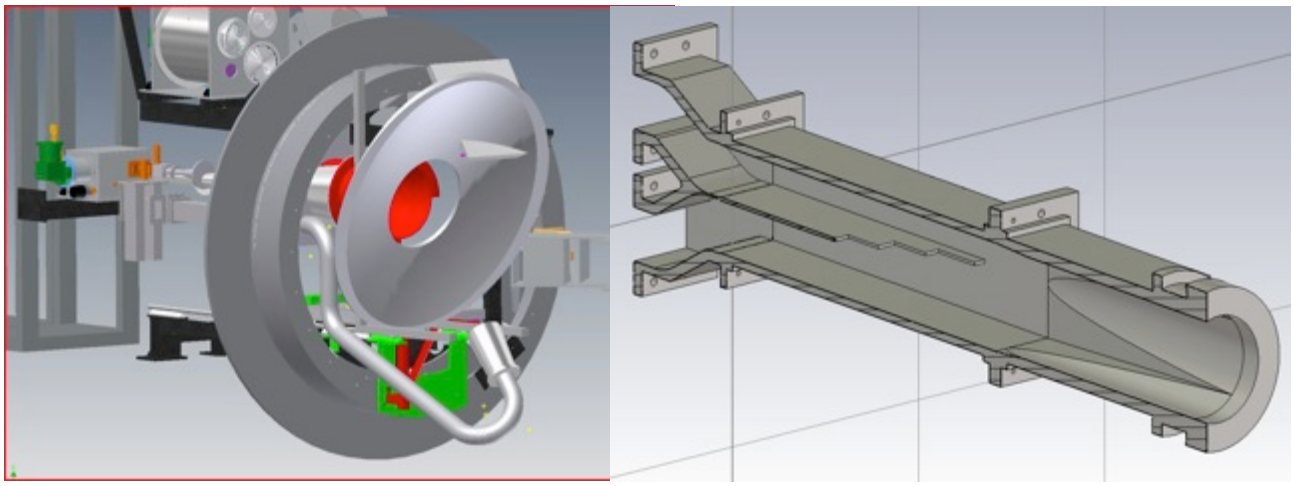


Figure 15. CAD drawing showing the view towards the focal plane of the 20 m with the tertiary mirror for S-band the new design of the horn and waveguides for S-band (left) and cross-section of the polarizer for S-band (right).

7.5 APEX SHeFI service mission

During the year the GARD group have prepared a major upgrade for the Swedish Heterodyne Facility Instrument (SHeFI) to be installed on APEX during the Bolivian winter shutdown in March 2014. The focus for this upgrade is replacement of the original cold IF amplifiers to state-of-the-art InP HEMT amplifiers obtained commercially. The upgrade covers APEX Band 1, Band 2 and Band 3 receivers and will hopefully improve not only the noise temperature by approximately 10% - 15% but will also improve performance towards the edges of the observing frequency band for each receiver channel.

7.6 New APEX Bolometer camera

The new ArTeMiS bolometer array (an ESO PI instrument from the CEA/Saclay bolometer group) was installed and commissioned in June-August 2013, partly on Swedish time (see Fig 16). The current version of the camera is operating at a wavelength of 350 micrometers with 1152 pixels. It is expected that ArTeMiS will be able to image the dust content in our Galaxy, as well as of that in more distant galaxies, with a much better efficiency than previously was possible. This instrument will be made available to PIs during future Swedish time (in return for granting some dedicated days of observing to the instrument team).

Fig 16. This image of the star formation region NGC 6334 ('Cats Paw' Nebula) is one of the first scientific images from the ArTeMiS instrument on APEX. The picture shows the glow detected at a wavelength of 0.35 millimetre coming from dense clouds of interstellar dust grains. The new observations from ArTeMiS show up in orange and have been superimposed on a view of the same region taken in near-infrared light by ESO's VISTA telescope at Paranal.

7.8 ALMA Band 5 Full Production Project

The ALMA band 5 receiver covers the frequency range 163 – 211 GHz and is centred on the para $H_2O(3_{13}\text{-}2_{20})$ line at 183 GHz; one of the few H_2O lines that can be observed from the Earth's surface (at the high altitude ALMA site under good weather conditions the transmission can approach 50% at the line peak). During the EU-funded ALMA Band 5 Enhancement Project the OSO GARD group delivered to ALMA in Chile six Band 5 receiver cartridge assemblies; this project was successfully completed during 2013. The receivers have been tested on the site and interferometric fringes have been obtained. The success of this project lead to an increased interest in the full deployment of Band 5 receivers on all ALMA antennas such that the ALMA Observatory board decided in Spring 2012 to finance this project as one of the first ALMA upgrades. In this new full production project GARD collaborates with the Netherlands Research School for Astronomy (NOVA). The contract was signed in February 2013 to produce 66 Band 5 cartridges of a slightly modified design compared to those made for the earlier EU project. The new project brings a total of 48 Mkr of ALMA central funding to GARD OSO in the period through till 2017. Work on this full production project started in earnest in the spring of 2013 and the first new receiver elements were being produced by the end of the year.

7.9 Local-tie of the Onsala 20 m telescope with GNSS

Two gimbal-mounted GNSS antennas were installed in the summer of 2013 on the 20 m telescope, one on each side. GNSS data were collected during several dedicated experiments and these data are currently being analysed to determine an independent local-tie between the reference points of the 20 m telescope and

the GNSS monument ONSA at Onsala. In November the two GNSS antennas were sent to Bonn and Hannover for absolute phase centre calibration.

7.10 Gravimeter laboratory

A gravimeter sensor suffered from a magnetisation change (an electronic problem in the feedback control loop) in February 2011 (detected autumn 2013); however a continuous reference base for the record can nevertheless be maintained as the repercussion on the time series can be modelled with four parameters. During April 22 and May 2 the gravimeter laboratory was used for measurement with the FG-5 portable absolute gravimeter, owned by Lantmäteriet, Gävle. The campaign served three purposes, re-measurement of gravity as a joint effort of the Nordic Geodetic Commission; calibration of the SCG; re-measuring the tie between the new pillar in the laboratory and the old one, for the last time before it is definitely abandoned. A reprocessed tide solution has to wait until mid 2014 because of the large covariance between gravity effects due to Polar motion and the solar annual tide (the model parameters representing these effects require independent estimates in order to constrain the long-term sensor behaviour ("drift").

7.11 Super-tide-gauge station

Preparations for installing a super-tide-gauge station at the Onsala site (see Fig 17), in collaboration with the Swedish Meteorological and Hydrological Institute (SMHI), have continued. A long-term agreement defining the investments, operating costs, data quality assessment, and archiving between SMHI and OSO was signed during the autumn of 2013. An application for permission to build the installation was submitted to the Kungsbacka municipality in November 2013.

Figure 17. Computer generated image of the super tide gauge station to be developed in collaboration between SMHI and OSO.

As a preparation for the final installation, and in order to gain experience handling and analysing tide gauge data, a bubbler tide gauge, or pneumatic bubbler gauge, was temporarily installed during the autumn of 2013 for sea level observations at the observatory. The bubbler tide gauge is of the type CS471 Compact Bubbler System (Campbell Scientific Inc.) and has a specified accuracy of ±3 mm over the actual measurement range. The bubbler is constructed to have compressed air, produced by a piston pump, flowing in a measuring tube into the water. The pressure created in the tube is then directly proportional to the water column above the bubble chamber and the height of the water level above the bubble chamber is calculated from the difference between the barometric air pressure and the bubble chamber pressure.

7.12 Investigations for possible future DORIS station at the observatory

The situation has not changed since last years report. There are uncertainties due to possible interference problems of Doppler Orbiography and Radio positioning Integrated by Satellite (DORIS) stations in the vicinity of radio astronomical telescopes. No final conclusions or recommendations have yet been reached in the geodetic VLBI community so the project still has a low priority.

7.13 New Hydrogen Maser

During 2013 we purchased a replacement Hydrogen maser (which provides the very accurate clock signal needed for running astronomical and geodetic VLBI). The maser it replaced was more than 20 years old, had had a serious failure in 2012 and was beyond its useful lifetime. The procurement process for a new H-maser was started in early 2013 with the contract going to the Russian company Kvarz. The maser was delivered in put in operation in August 2013.

8) SKA Design Project

OSO has continued and deepened its involvement in the Square Kilometre Array (SKA), an international project to build the world's largest m- and cm-wave radio interferometer (a project on the ESFRI list, and top-ranked on the Astronet technological roadmap for astronomical infrastructures). Since June 2012 OSO represents Sweden in the SKA Organisation Ltd, a British company that will lead the SKA project during its pre-construction/final design phase through to the end of 2016. At the end of 2012 Onsala obtained a VR planning grant to support SKA design work in 2013 and 2014. This grant has been used in 2013 to finance the involvement of staff from the Chalmers' antenna group in SKA design studies. Additionally OSO participates in a work package of the Joint Research Activity DIVA within the Radionet 3 EU project to develop wideband feeds for VLBI – and whose frequency range overlaps that needed for SKA purposes.

In March 2013 the SKA Organisation released a call for tenders for the design stage of Phase 1 of SKA with a deadline of June 2013. The final design phase will continue for three years and deliver "blue prints" for building SKA Phase 1. OSO participated in two international consortia which successfully bid. The first was as a member of the SKA Dish Consortium (SKADC) formed by a number of institutions and companies across Europe, South Africa, Australia, China and Canada. Within this work consortium OSO is responsible for the design and

prototype fabrication of feed and receiver package for SKA Band 1, 350-1050MHz. Within this project are also involved researchers from the Chalmers Antenna Group, within the Signals and Systems Department (0.8FTEs in total), and also manpower from Omnisys Instruments AB (0.5FTEs) funded from the VR project grant.

The second successful consortia submission is led by Chalmers. This involves an Advanced Instrumentation Program (AIP) for the design of Wide Band Single Pixel Feeds (WBSPF). OSO again collaborates closely in this project with staff of the Chalmers Antenna group and also the Chalmers Microelectronics laboratory low noise amplifier group. OSO has the project management role in a consortia formed from research institutions from Sweden, Germany, Holland and China. Within the WBSPF consortia, OSO is technically responsible for the cryogenic integration and tests of the feed and LNA package for the 1.6-10 GHz frequency range.

Work within both the SKA Dish and WBSPF work packages both officially started in November 2013. Previous to this preparatory work started in January, funded primarily by a VR SKA technical planning grant, on developing the technical concepts which were part of the two work package proposals submitted in June. In addition a prototype low frequency WBSPF of the 11-feed type was built at the observatory and important advances made is developing new feeding structures for the 11-feed. New software and computer hardware for doing electromagnetic simulations of antennas was purchased and installed. The VR project grant funded staff were also instrumental in defining the metrics that will be used for determining the final optical configuration of the SKA antennas. Staff also made important contribution to internal planning meetings of the Dish Consortium in Sydney, Australia and Penticton, British Columia, Canada.

9) Twin-telescope system for geodetic VLBI at Onsala

In the activity report for 2012 we informed about the KAW grant (29.73 Mkr) awarded to OSO to build a twin telescope system for geodetic VLBI consistent with the new VGOS standard. This new standard will improve positional accuracies by an order of magnitude relative to existing geodetic VLBI. A request for building permits for the two telescope sites close to our 25 m telescope were submitted in Spring 2013. The Kungsbacka local council approved this request but the county of Halland then appealed the decision to grant exemption from the law for shoreline protection. The county's environmental department concluded that the eastern antenna site would be too close to wetlands where wading birds are present, in particular the Northern Lapwing (vanellus vanellus) and that the telescope could impact breeding of these birds. This ruling caused Halland county in June 2013 to withdraw the exemption from the law for shoreline protection. Subsequently in 2013 we searched for an alternative location for this telescope, without compromising the sky visibility. In this process we involved experts and the authorities in discussions in order to uncover any additional problems that may impact the permissions needed. An updated proposal was submitted to Kungsbacka municipality in December 2013. A computer generated view of the Onsala Twin Telescope according to the present proposal is shown in Figure 18. The procurement papers for the antennas are prepared so these can be sent out as soon as the legal issues are resolved, it is hoped to formally begin the project in July 2014.

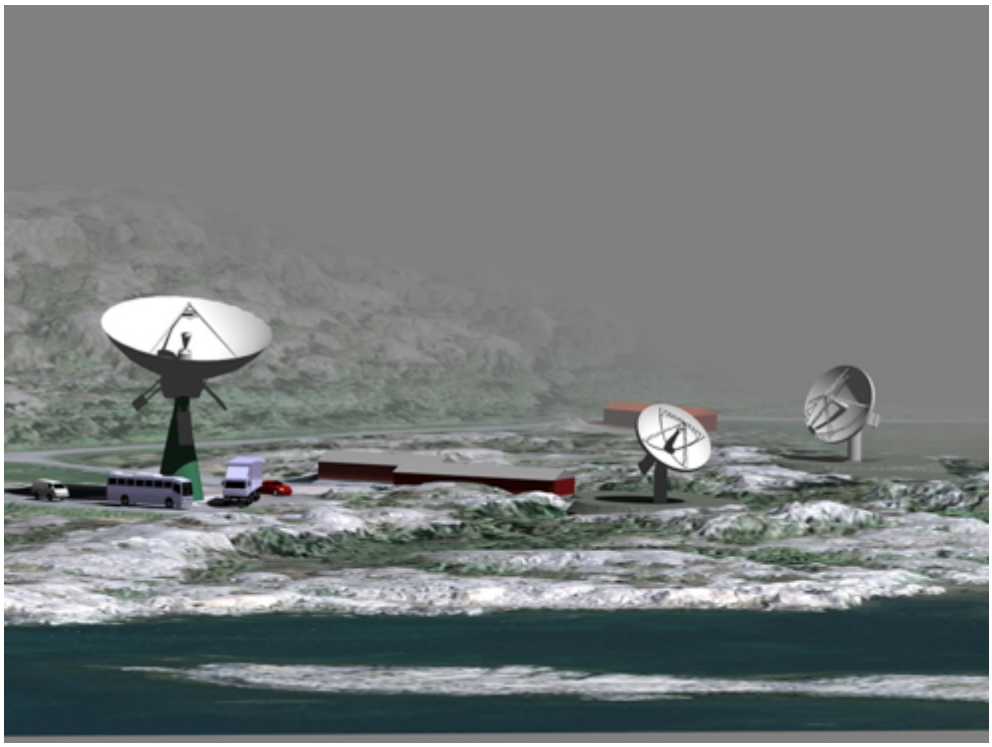


Figure 18. Computer generated image of the Onsala Twin Telescope (OTT) system for geodetic VLBI. The two 12 m geodetic VLBI telescopes are shown on the right part of the picture while the existing 25 m radio telescope is to the left. The 12 m telescope in the middle is at the new proposed location, slightly shifted to the West as compared to the original site reported in last year's activity report. The view is from the south direction.

10) Preparations for replacement of 20m telescope radome

As proposed in the activity plan for 2013 investigations were carried out into the most practical and cost effective way to replace the aging 20 m telescope radome. A market survey showed that for a radome of the size needed to enclose the 20 m telescope the only practical option was a wire frame radome of the type we presently have (the other potential option of an inflatable radome not being possible). A major concern is that the installation of the new radome should not expose the 20 m telescope to the elements; fortunately for such a wire frame design it is possible to replace only a few panels at the time from the inside of the radome. Given the result of the market survey the procurement process was started at the end of 2013 with the goal installation of the replacement radome being completed in the second half of 2014.

11) Membership on International committees

During 2013 OSO was involved in the following international boards and coordinating committees. The observatory Director (Hans Olofsson till 30th November 2013 and John Conway from 1st December) serves on many of these boards.

- *The European VLBI Network (EVN) for* astronomical VLBI (The Director is a board member. Michael Lindqvist is chairman of the Technical Operations Group (TOG) and member of the Observing Programme Committee)
- *The Joint Institute for VLBI in Europe (JIVE),* a Dutch foundation that operates the EVN correlator in Dwingeloo (NL) and supports the EVN activities (Hans Olofsson was chairman of the board till stepping down as director on November 30th and replaced by the new director as an ordinary board member).
- *The APEX project* where three partners operate a 12 m sub-mm telescope in northern Chile (the Director is a board member, and Per Bergman is the Swedish project scientist)
- *The International LOFAR Telescope (ILT)* Board, which sets up the roles for the operation of the ILT (John Conway is a board member).
- *NEXPReS,* an EU-financed project which promotes the use of eVLBI (John Conway was a board member, till the project end in June 2013).
- *RadioNet3,* an EU-financed I3 project, which coordinates all of Europe's leading radio astronomy facilities (The Director is a board member, Michael Lindqvist represents the EVN TOG and CRAF)
- *European SKA Consortium*, which promotes the European involvement in the SKA project (the Director is board member)
- *The SKA Organisation (SKAO),* the British company that is responsible for the SKA project in its pre-construction phase (Hans Olofsson and John Conway were board members till the end of November after which John Conway became the only member pending the selection of a second member). Hans Olofsson was a member of the Funding Task Force and the Hosting Agreement Task Force, Maria Karlsson from the Chalmers Department of Earth and Space Sciences administration is member of the Finance Committee).
- *SKA Dish Design Consortium* – Board member is John Conway
- *SKA Wide-Band Single Pixel Feed Design Consortium* - Board member is John Conway
- *International VLBI Service for Geodesy and Astrometry (IVS*), which operates geodetic VLBI (Rüdiger Haas is board member)
- *International Earth Rotation and Reference Frame Service (IERS*) (Rüdiger Haas is board member and committee member)
- *Nordic Geodetic Commission (NKG)* through the working group on infrastructure (Rüdiger Haas is committee member)
- *The European VLBI Group for Geodesy and Astrometry (EVGA*) (Rüdiger Haas is chair person)
- *Global Geodetic Observing System (GGOS) Inter Agency Committee (GIAC)* (Hans Olofsson was board member in 2013 but will be replaced by Rüdiger Haas)

12) RadioNet3 EU Project

A new EU funded RadioNet3 project (Advanced Radio Astronomy in Europe) activity began in 2012 and continued through 2013. In total RadioNet3 covers the period 2012 – 2015 and is a EU Integrated-Infrastructure-Initiative-funded network of all the major radio astronomical observatories in Europe (and some beyond). Radionet 3 follows on from a number of successful similar activities over the years. Its aim is to support the use of the radio astronomical facilities as well as to support R&D on new radio astronomical instrumentation and methods. From this activity OSO gets TransNational Access (TNA) funding for its operation of APEX and its contribution to astronomical VLBI. It also takes part in two Joint Research Activities: DIVA (Developments in VLBI Astronomy) and AETHER (Advanced European TeraHertz Heterodyne Receivers), described respectively in Sect 6.1 and 6.2. Finally OSO participate in several networking activities within RadioNet3.

13) Workshops, schools, etc

A summer school organised at Onsala jointly between the Chalmers Radio Astronomy and Astrophysics group and OSO entitled 'Molecules in Space' took place in June as part of the Swedish Astrobiology network and used the 20 m telescope for observational projects.

Onsala Space Observatory also supported the EGU and IVS Training school on VLBI for Geodesy and Astrometry, held at Aalto University, Espoo (Finland) and the Finnish Geodetic Institute, Masala (Finland), in March 2013. The support was of financial and operational character. The DiFX software correlator installed at Onsala was used for student classes.

14) Education

The observatory staff do not generally take part in the academic teaching at Chalmers (except for a few lectures on specialized radio astronomy observing techniques). The national facility does however support teaching by making a small fraction of the time on the telescopes available for exercises by students on Chalmers and other Swedish academic courses. The staff are also sometimes involved in teaching and providing exercises at specialised graduate level schools that are organised from time to time at the observatory. Specifically at Chalmers, the 20 m telescope and SALSA are used in astronomy courses, the 25 m telescope in a satellite communication course, GNSS equipment in bachelors thesis projects and a satellite positioning course, and laboratory equipment in courses on microwave, millimetre wave and THz technology. Additionally during the year students from the universities in Stockholm and Lund visited the observatory to carry out observations and/or to learn about radio astronomy.

15) Outreach

Outreach activities to children and the general public are important missions of the Onsala national facility. Outreach at Onsala is led and coordinated by a half time position (0.5 FTE) employed by the OSO national facility but also uses manpower resources (0.9 FTE) bought in from the PhD students from the Radio Astronomy group at Chalmers (this effort is funded by the Chalmers financial contributions to OSO not those of VR). Outreach encompasses a wide range of tasks including site visits, lectures and media interaction.

In 2013, a total of 2130 people visited the Onsala site, its telescopes and exhibition. In total 1830 visitors took part in 73 guided tours, the largest number of which were schoolchildren in all age groups. Several outreach events were organised during the Gothenburg Science Festival in April. During one Sunday we set up a control room for our telescopes to the Nordstan shopping centre in central Gothenburg. A steady stream of members of the public asked questions met scientists and tried out remote observations with our remotely controlled small SALSA antenna at Onsala. Two events were held during the national Day and Night of Astronomy on 28 September. For the second time we organized the star party Onsala stjärnträff during which 13 enthusiasts from the general public carried out radio observations and learned from both each other and from invited speakers. A trio of talks was held at Universeum in Gothenburg.

During the year Onsala staff were interviewed frequently by newspapers and radio, occasionally TV, about astronomical subjects of popular interest. In addition, staff gave a number of public talks about astronomy across the country. Staff members wrote articles for the magazine Populär Astronomi. We have continued our presence on social media (Facebook and Twitter for spreading news, and Flickr for images). We answered many queries from journalists about astronomy in general and the observatory in particular.

High school students and classes from Sweden and elsewhere in Europe were the majority of the 57 users of our SALSA radio telescopes. In 2013 these were booked for an average of 76 hours every week, mostly by users connected remotely from as far away as Bangladesh and Honduras and carrying out projects observing interstellar gas in the Milky Way. Three 14 – 15 year olds came to the observatory as part of their work experience (prao) weeks in November.

A number of press releases were issued presenting research with Onsala facilities and by Chalmers astronomers. These covered the detection of the potential parent bodies of free-floating planets, the best measurement of the temperature of the cosmic microwave background in the past; the location of the coolest layer of the nearby star Alpha Centauri (coordinated with ESA), ALMA observations of a blazar jet (coordinated with ESO), the discovery of a magnetic jet in a planetary nebula, and Sweden's membership of the SKA. These led to many news articles on the internet and a number of reports in print media, primarily in other countries but also in Sweden.

Chalmers' astronomers carried out a program of comet observations, intended to be both of scientific and public interest, during spring and winter of 2013. This led to coverage on national radio and culminated in a series of reports on the Chalmers science blog 'Forskning pågår' ('Science in progress') during observations of the comet C 2012/1 (ISON) at APEX and with the 20 m telescope

in Onsala **in** connection with its close approach to the sun in November.

16) Changes in organisation

On November 30th Prof Hans Olofsson stepped down as director of the National Facility after 8 years in the position. From 1st December the new director is Prof John Conway who been appointed initially for a five year term. On Dec 31 the Chairman of the Steering Committee of the observatory Lars Leijonborg stepped down, his replacement is Kjell Möller who is appointed for a three-year term, the members of the steering board were also re-appointed by VR and Chalmers for a concurrent 3-year term.

17) Importance to society

OSO supports basic research within astronomy and geoscience. Both astronomy and geoscience research have a strong appeal to the curiosity of people of all ages, and this is used in our outreach activities as described above. In addition, geoscience is of importance for understanding the system "Earth", and therefore of importance for e.g. climate applications, such as monitoring of ozone in the atmosphere and determining changes in the absolute sea level. There is also the potential to predict earthquakes. Geodetic VLBI provides the fundamental terrestrial reference frame, which is the base for all navigational applications. As a by-product of its VLBI activities the observatory also contributes to establishing the official Swedish time and international time, through two hydrogen maser clocks and one caesium clock. The OSO staff and instruments are involved in education at all levels from bachelor to graduate studies at Chalmers, and through organised schools.

18) Importance to industry

The activities at OSO are not directly aimed at industry-relevant products. Their importance lies rather in the spin-off products, in particular in microwave engineering, and in collaborations with local high-tech companies, such as Omnisys Instruments AB and the Low Noise Factory. The work on a cryogenic broadband feed system based on the 11-feed, which for OSO has relevance for both geodetic VLBI and the SKA, has lead to the formation of a spin-off company, and Omnisys develops a cryogenic broadband feed system specifically for geodetic VLBI together with OSO. Because of the large scale of the SKA project it is expected that this will have a large financial payback to Swedish industry especially if Sweden fully joins the SKA construction phase. OSO staff also contributes to 'continuing professional development' of relevance to industry.

19) Financial account

OSO gets most of its operation funding from the Research Council (VR) and Chalmers. The division of expenditures is such that the Chalmers funding takes care of rent, electricity, administration, central overhead, etc. There is in addition a small contribution to operations funding within the EU-financed RadioNet3 project via its Trans National Access (TNA) element, which supports international access to APEX and the use of the OSO telescopes in EVN VLBI.

VR income, operation	*37 140* kkr
Expenditures on VR grant:	
Salaries	19 260 kkr
APEX central operation	4 944 kkr
LOFAR, central operation	765 kkr
JIVE, central operation	1183 kkr
SKA, membership fee	2218 kkr
ESF, Frequency manager	163 kkr
Data fibre links to Stockholm/Netherlands[1]	653 kkr
Travel	789 kkr
Equipment	3403 kkr
Supplies	2337 kkr
Services	413 kkr
Buildings	203 kkr
Telephones, office mtrl, etc	288 kkr
Total	36 619 kkr
Chalmers income, operation	*16 600* kkr

In addition to the above operations funding the observatory is involved in a number of multi-year projects, the total values and periods of these projects are given below.

Project funding:

VR, LOFAR equipment, 2008 – 2013	6 960 kkr
VR Planning Grant (SKA) 2013-2014	6 600 kkr
Chalmers, EU support	456 kkr
EU, RadioNet3, 2012 – 2015	6100 kkr
ESO ALMA Band 5, 2013 – 2017	41074 kkr
EU, NEXPReS, 2010 – 2013,	287 kkr

Acronyms

AETHER	Advanced European TeraHerz Heterodyne Receivers
ALMA	Atacama Large Millimetre/submillimetre Array (Chile)
ARC	ALMA Regional Centre
APEX	Atacama Pathfinder Experiment (Chile)
DBBC	Digital Base Band Converter
DIVA	Developments In VLBI Astronomy
EGU	European Geosciences Union
ESO	European Southern Observatory
EVN	European VLBI Network
GARD	Group for Advanced Receiver Development
GGOS	Global Geodetic Observing System
GIAC	GGOS Inter Agency Committee
GMVA	Global Millimeter VLBI Array
GPS	Global Positioning System
GNSS	Global Navigational Satellite Systems
HEB	Hot Electron Bolometer
HEMT	High Electron Mobility Transistor
ILT	International LOFAR Telescope
IGS	International GNSS Service
IRAM	Institut de Radioastronomie Millimetrique
IVS	International VLBI Service for Geodesy and Astrometry
JIVE	Joint Institute for VLBI in Europé (NL)
KAW	Knut and Alice Wallenberg foundation
LOFAR	Low Frequency Array
NRAO	National Radio Astronomy Observatory (USA)
NEXPReS	Novel Explorations Pushing Robust e-VLBI Services
OSO	Onsala Space Observatory
RadioNet3	Advanced Radio Astronomy in Europe
SALSA	Such a Lovely Small Antenna
SEST	Swedish-ESO Submillimetre Telescope (Chile)
SHeFI	Swedish Heterodyne Facility Instrument for APEX
SIS	Superconductor-Insulator-Superconductor (receiver technology)
SKA	Square Kilometre Array
TAC	Time Allocation Committee
TNA	Trans National Access
ToO	Target of Opportunity
VLBI	Very Long Baseline Interferometry
VGOS	VLBI2010 Geodetic Observing System
WVR	Water Vapour Radiometer